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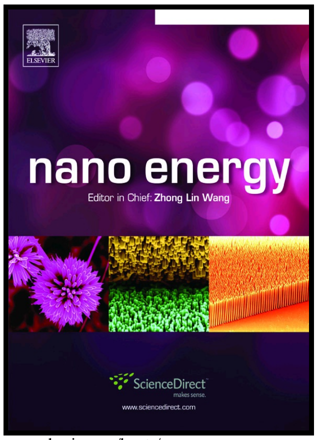

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Flexible piezoelectric nano-composite films for kinetic energy harvesting from textiles

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Abstract
This paper details the enhancements in the dielectric and piezoelectric properties of a low-temperature screen-printable piezoelectric nano-composite film on flexible plastic and textile substrates. These enhancements involved adding silver nano particles to the nano-composite material and using an additional cold isostatic pressing (CIP) post-processing procedure. These developments have resulted in a 18% increase in the free-standing piezoelectric charge coefficient d_{33} to a value of 98 pC/N. The increase in the dielectric constant of the piezoelectric film has, however, resulted in a decrease in the peak output voltage of the composite film. The potential for this material to be used to harvest mechanical energy from a variety of textiles under compressive and bending forces has been evaluated theoretically and experimentally. The maximum energy density of the enhanced piezoelectric material under 800 N compressive force was found to be 34 J/m^3 on a Kermel textile. The maximum energy density of the enhanced piezoelectric material under bending was found to be 14.3 J/m^3 on a cotton textile. These results agree very favourably with the theoretical predictions. For a 10 cm x 10 cm piezoelectric element 100 μm thick this equates to 38 μJ and 14.3 μJ of energy generated per mechanical action respectively which is a potentially useful amount of energy.

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Keywords: **Piezoelectric, nano-composite, energy harvesting, textiles, screen printed**

1. Introduction

Electronic textiles (e-textiles) are a form of wearable technology that has the potential to revolutionise the wearable technology sector. E-textile solutions face the same challenge as with all wearable devices, namely that of supplying electrical power. At present the only solution is to use batteries and whilst this suits rigid wearable devices, they are less compatible with flexible textiles and the requirement to periodically charge the battery is an ongoing inconvenience. Energy harvesting potentially provides an alternative power source that could replace or augment a battery solution. This paper explores the potential of a flexible piezoelectric film screen printed onto a textile for harvesting mechanical energy from the textile and converting it into electrical energy [1-3]. One application of such an approach would be to harvest the kinetic energy present in human movement that would cause clothing fabric to flex and compress. The compressive and bending forces would be transferred to the piezoelectric film enabling the mechanical to electrical energy transduction process to occur. Piezoelectric transduction is a very widely used method for harvesting mechanical energy and many example devices have been published including cantilever based structures with bonded bulk [4] and screen printed [5] lead zirconate titanate (PZT). More recently, nano-scale materials have been explored such as ZnO nanowires [6] and BaTiO3 nanofibres aligned within a flexible polydimethylsiloxane (PDMS) matrix [7].

To be used in such an application, the piezoelectric materials needs to be flexible thereby minimising its effect on the feel of the textile and the user's comfort. The common piezoelectric materials, such as PZT ceramics, possess excellent dielectric and piezoelectric properties but are physically hard and brittle and are inherently unsuitable for such an application. Alternative polymer piezoelectric materials, such as polyvinylidenefluride (PVDF) and associated co-polymers, are flexible and can be cured at low temperature, which is suitable for use with fabrics. PVDF yarns have also been

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